CHARACTERISTICS OF AVERSIVE THRESHOLDS MEASURED BY A TITRATION SCHEDULE¹

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Three variables were studied for their single and joint effects on aversive thresholds obtained by a titration schedule with electric shock as the aversive stimulus. One variable was the interval between the periodic increments in shock amplitude. Another was the size of this increment. The third was the size of the decrement produced when the subject responded. Both monkeys and humans tolerated more shock at the shorter increment-to-increment intervals than at the longer ones, confirming rat data previously obtained. Reducing the decremental step size also led to an increase in the amount of shock tolerated by monkeys. In addition, simply reducing both incremental and decremental step size without changing the interval between increments led monkeys to tolerate more shock. The attempt to explain these data was based on the changes that such manipulations might produce in the amount of avoidance behavior elicited.

Certain properties of aversive stimuli can be studied by a technique called a titration schedule. This term refers to an arrangement by which increments in the amplitude of the stimulus are automatically programmed, and decrements in amplitude follow designated responses of the subject (S). The output of such a system reflects the S's tolerance of the aversive stimulus. This technique is a direct descendent of the technique devised by Békésy (1947) and, independently, by Oldfield (1949).

If the aversive stimulus is a periodically increasing electric shock to the feet, rats will press a lever to reduce its amplitude (Weiss and Laties, 1958). The amplitude they tolerate, however, depends upon how rapidly the shock level rises; rats tolerate more shock when the increments come more often (Weiss and Laties, 1959). Furthermore, an analgesic effect of aspirin could be observed only when the interval between increments was relatively short (Weiss and Laties, 1961a). The experiments reported here investigated whether

monkeys and humans also tolerate more shock when the interval between increments is reduced, and whether the size of the increment (and decrement) is important.

METHODS

Monkeys

Data were obtained on three sets of monkeys in two different situations. One set was studied in a modified rat box (Foringer and Company, Rockville, Maryland). This set consisted of two male *Cebus capucinus* and one male *Saimiri sciurea*. The box measured 10 by 11 by 12 in. and contained one lever 3 in. above the floor on one side. The lever was surrounded by a guard so that it could not be pressed by the monkey's tail. The shock stimulus was delivered through the stainless steel rods that comprised the floor of the chamber via a cam-type scrambling device that continuously switched the polarities of the rods. Two other sets of four monkeys each were studied in primate restraining chairs. One set consisted of one female *Macaca nemestrina*, one male *Erythrocebus patas*, one male *Cercopithecus ethiops*, and one female *Guenon*, probably *Cercopithecus mitis*. A different set of four was used in the experiment on decremental step size. All of these were female specimens of *Macaca nemestrina*. The shock stimulus was delivered to the feet through aluminum shoes into which the feet were securely strapped

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(Weiss and Laties, 1962). Before a session, the soles of the feet and the shoes were cleaned with ether or ethanol, and a non-corrosive electrode paste (EKG-Sol) was then applied. This reduced the monkey's impedance to about 3,000 ohms when the stimulating current was about 2 ma. The chairs were enclosed in large, sound-deadened chambers in a room adjoining the programming and recording equipment.

Humans

The three human subjects were all young males. Two were medical students; one was an undergraduate college student. They were paid \$2.50 per session for their services. The stimulus was delivered to the forearm through electrodes developed for telemetering ECG data. These are so made that contact of the electrode with the skin is made through a layer of electrode paste. Such a feature is useful because it prevents skin burns, and because the stimulating surface remains fairly constant in spite of muscle movements. The S sat in a chair during the experiment and responded by pulling a Lindsley manipulandum (R. Gerbrands Company, Arlington, Mass.) mounted on a column attached to a base near his legs.

Training Procedures

Monkeys. The monkeys were started on a schedule whereby the shock level rose by a fairly small step ($\frac{1}{50}$ of the maximum shock) once every 20 sec. Each time the monkey struck the lever, the shock current fell to zero. When this behavior was firmly established, as demonstrated by the maintenance of a stable shock level, the decrement in shock level produced by a response was reduced. When the monkey's behavior again stabilized, the decrement was again reduced. This procedure was continued until the decremental steps were the same size as the incremental steps. Once this point was reached, the interval between increments was gradually shortened until the monkey was able to maintain a stable threshold at the highest rate of rise used in these experiments (a rise of one step every 2 sec). All three sets of monkeys were given considerable experience on titration schedules before the present series of experiments began in order to decide on the range of values to be assigned to each parameter.

Humans. On their first exposure to the situation, the human Ss were told that a shock would be delivered to the forearm and that they could control the shock intensity by pulling on the manipulandum. They were also told that the purpose of the experiment was to observe changes in skin impedance as a function of different stimulus characteristics of the electric shock. They were instructed to maintain the electrical stimulus within what was termed the "comfort zone," that is, a stimulus level well below pain threshold. This generally gave rise to a sensation described as tingling or itching. Each S was given at least two 40-min practice sessions to ensure that he could maintain a stable shock level. Data were then gathered on the effect of varying the intervals between increments. Once these data were obtained, another series of sessions was conducted in which the Ss were told to keep the stimulus at a point just below pain threshold, that is, "just below the point at which it hurts."

Stimulus Characteristics

For all the experiments the stimulus was 60 cycle AC, 700 v, delivered through a high series resistance so that changes in the impedance of the S produced relatively minor changes in the current passing through the skin. For the experiments in the box the maximum shock level was 1.1 ma rms and the series resistance was 636 K. For the monkeys in the chairs and for the humans the maximum shock level was 5 ma rms and the series resistance was 140 K. During an experiment, an oscilloscope was used to measure the voltage drop across the S and across a 1000 ohm resistor in series with the S.

Programming Methods

Changes in the level of shock applied to the S were produced by a Grason-Stadler recording attenuator with its output shaft connected to a variable transformer in the stimulating circuit (see Fig. 1). Pulses to the recording attenuator from a timer increased the shock level by turning the output shaft in one direction. Pulses from a circuit connected to the S's manipulandum drove the output shaft in the opposite direction and produced decreases in the stimulating current. The increment-to-increment interval (i-i interval) was regulated by another timer. The sizes of both

Fig. 1. Block diagram of the programming and recording equipment.

the incremental and decremental steps were varied by electronic timers that controlled the length of the pulses activating the output shaft. The step size for increments and the step size for decrements could be varied independently. In addition, by means of a predetermining counter, it was possible to vary the number of responses necessary to produce a decremental pulse.

Data Processing

The output of the stimulator was recorded on the strip chart of the Grason-Stadler recording attenuator. The S's responses were recorded on a Gerbrands cumulative recorder. To obtain the amount of shock tolerated during any one session or part of a session, an analog-to-digital converter translated the stimulus amplitude into a pulse rate linearly related to amplitude. These pulses were recorded on a printing counter and on a second cumulative recorder. By counting these pulses, a quantity was obtained that represented the integral of the curve traced out on the recording attenuator.

RESULTS

Joint Effects of Variation in Step Size and I-I Interval

Two experiments examined various combinations of i-i interval and step size. The first included i-i intervals of 2 and 10 sec and six step sizes ranging from $\frac{1}{500}$ to $\frac{1}{14}$ of the maximum shock. That is, the shock rose from

zero to the maximum current in 500 steps at the smallest step size and in 14 steps at the largest step size. The size of the decremental step was equal to the size of the incremental

Fig. 2. Integrated shock as a joint function of increment-to-increment (i-i) interval and step size. (Incremental step = decremental step.) The height of the bar designates the mean of three monkeys. Each symbol represents an individual monkey. The point for a single monkey represents the mean of three 1-hr sessions.

step. Each monkey underwent the 12 combinations of conditions in a different order. Figure 2 shows the results obtained with the three

monkeys that were studied in the modified rat box. Each point gives the mean for three 1-hr sessions contributed by each of the three

Fig. 3. Segments from attenuator records made at $i-i$ 10 sec with step sizes indicated to demonstrate variation in cumulative record smoothness as a function of step size. Each segment equals 15 min. Note: attenuator time reads right to left and cumulative record time reads left to right.

monkeys. The step sizes are given as the proportion of the maximum current occupied by each step.

At each step size, an i-i interval of 2 sec caused the monkeys to tolerate more shock than an i-i interval of 10 sec. All three monkeys showed this tendency at every step size with the only exception occurring at a step size of .034. Thus, in an enclosure that allows a monkey to move freely, decreasing the time between increments increases the amount of shock that the monkey tolerates, just as it does in the rat. In addition, the smaller step sizes appeared to engender a greater integrated shock than the larger ones, a tendency that was, however, much more apparent at i-i 2 sec than at i-i 10 sec.

Figure 3 shows another effect of step size that was typical of these Ss. At an i-i interval of 10 sec, the larger step sizes resulted in a much smoother cumulative record than the smaller ones. The reason for this is that the monkeys tended to let the shock drift upward when the step was small and then brought it down with a rapid series of responses. When the step was large, the monkey had to respond much more regularly to keep the shock from rising to very aversive levels. When the shock level rose rapidly, however, as at i-i 2 sec, this difference in regularity as a function of step size was greatly reduced, probably because aversive levels of shock were reached much sooner, regardless of step size, when the animal failed to respond.

Because of the possibility that these results might be due to some peculiarity in the situation arising from factors such as the method of scrambling the shock or the physical features of the enclosure, we also explored the interaction between step size and i-i interval with monkeys in chairs to whom the shock was presented by an electrode shoe. The step sizes were .005 and .034 and the i-i intervals 2 and 10 sec. The incremental and decremental step sizes were equal. An additional set of combinations was introduced by using an i-i interval of 10 sec with a fixed ratio of five responses required to produce a decrement. With this contingency the monkey had to respond on the average of once every 2 sec to keep the shock at a constant level. Thus, in terms of response rate, such a schedule is equivalent to i-i 2 sec. The results for this series are based on the last of three 1-hr sessions for each condition.

Figure 4 gives the data for all four animals and Fig. 5 shows the attenuator record of one monkey.

In the comparison of i-i 2 sec and i-i 10 sec, with each response producing a decrement, it can be seen that even with a monkey immobilized in a chair so that its feet were in constant contact with the stimulating surface (as monitored by an oscilloscope), more shock was tolerated at i-i 2 sec than at i-i 10 sec. Furthermore, there was again a pronounced tendency for more shock to be taken at the smaller step sizes than at the larger ones. This tendency did not seem more apparent at i-i 2 sec than at i-i 10 sec, although it did in the previous experiment. Imposing the fixed ratio at i-i 10 sec raised the tolerated shock to a level higher

Fig. 4. Integrated shock as a function of i-i interval, step size, and fixed ratio. (Incremental step = decremental step.) The height of the bar designates the mean of four monkeys. Each symbol represents the performance of an individual monkey during a 1-hr session.

Fig. 5. Sample attenuator records with the step sizes and i-i intervals noted. Time reads from right to left. Note that at the combination of step size = .005, i-i interval = 10 sec (FR 5), the shock level rises throughout the session, suggesting partial extinction.

than that tolerated when the schedule was continuous reinforcement. This also confirms the rat data obtained earlier when a similar ratio requirement was imposed (Weiss and Laties, 1959).

Variation in Decremental Step Size

Another method can be employed to vary the amount of responding required to counteract a rising shock level besides changing the i-i interval or the number of responses needed to produce a decrement. The amount that the shock decreases after a response can be varied. Variation in this parameter was studied by a program on which the decremental step size alternated every 20 min from .02 to .11 for a total of 16, 20-min periods. The i-i interval remained 2 sec and each shock increment occupied .02 of the maximum shock. The mean

Fig. 6. Integrated shock as a function of decremental step size. The i-i interval was 2 sec and the incremental step size remained at .02. The decremental step size alternated every 20 min between .02 and .11. The height of the bar represents the mean of four 20-min segments with each step size. The symbols represent the means for the individual monkeys.

Fig. 7. Sample attenuator record comparing decremental step sizes of .02 and .11. The incremental step size remained at .02. The size of the decremental step alternated every 20 min.

integrated shock per period is shown in Fig. 6 and parts of a sample record are in Fig. 7.

As might be expected from the previous experiments, more shock was taken with the smaller decrement. The records also disclosed, however, what is perhaps a more interesting point. With the larger decremental step, the monkeys tended to begin to respond at a lower shock level than with the smaller step. That is, although lower "troughs" in the record would be expected with the larger step, simply because the shock falls more, the "peaks" were also lower. This indicates that as the shock rose from a trough, the monkey tended to initiate a series of responses at a lower shock level with the large decremental step in effect than with the small one in effect. Such behavior resembles that shown in Fig. 3; *i.e.*, there was more tendency for the monkeys to allow the shock to drift upwards when the incremental step was small than when it was large.

Effects in Humans of I-I Interval Variation and Instructions

All three human subjects, when instructed to maintain the stimulus within the comfort zone, maintained a higher shock level with *i-i* 2 sec than with *i-i* 10 sec. This is shown in Fig. 8 (left). The attenuator records are shown in Fig. 9. Thus, with this set of instructions, the human data duplicate those obtained with monkeys and rats.

In order to determine whether this effect might have been produced by the instruction

Fig. 8. Integrated shock levels for three human Ss under two different sets of instructions ("comfort zone" and "pain threshold") and *i-i* intervals of 2 and 10 sec. Each point is based on one 40-min session. The height of each bar represents the mean for that condition.

Fig. 9. Attenuator records made by human Ss under instructions to maintain shock level within the comfort zone. Time reads right to left and each segment represents a 40-min session.

given the Ss, they were studied again with another set of instructions. This time they were told to maintain the shock level at a point just below the level that caused pain. As can be seen in Fig. 8 (right), they still displayed a unanimous tendency to accept more shock at $i-i$ 2 sec than at $i-i$ 10 sec. Attenuator records are shown in Fig. 10.

DISCUSSION

When Ss must respond more frequently to counteract a rising shock level, they tolerate more shock. Before discussing this finding specifically, however, we should like to discuss some general features of the experimental situation.

One of the most puzzling aspects is why Ss tolerate any substantial shock at all. In earlier experiments with rats we would often observe them jumping about on the grid floor, squealing, and giving other indications that the

shock had reached an aversive level. At the same time, they continued to respond frequently enough to keep the shock from rising further. All the Ss have to do to maintain the shock amplitude at a steady level on a titration schedule is to match his mean response rate to that of the timer that programs the increments. The rats often brought the shock level close to its minimum value by a long burst of responses. Yet, instead of maintaining it at that value by subsequently matching the rate of increase, they would stop responding until the shock became noticeably aversive again, then bring it down with another rapid train of responses. Monkeys proved not very different from rats; they were often observed pressing the lever in the box and squealing as their feet jerked up and down on the grid. The monkeys confined to the chairs displayed similar behavior. We could sometimes see the feet twitching, hear the monkey squealing, and yet observe the animal keeping the

shock amplitude at this apparently noxious level.

This phenomenon is not confined to exteroceptive stimulation. Boren and Malis (1961) have studied aversive thresholds by implanting electrodes in the midbrain close to the spino-thalamic tracts. These experimenters were struck by the similarity of the titration procedure to the discriminated avoidance procedure in that the lower amplitudes of shock could serve as a warning signal for the higher amplitudes. To determine the point at which pure fractional escape was being generated, they limited the peak to which the current could rise, increasing it from time to time until they finally reached a point at which lever pressing did not extinguish. This point, presumably, was the one which unmistakably elicited escape behavior. In this

way they were able to estimate how much of the time the monkey kept the stimulus at a noxious level when it was on a titration schedule. It turned out that monkeys did accept noxious levels part of the time. Boren and Malis also found an increase in the amount of current tolerated when a ratio contingency was imposed, a result equivalent to ours.

The fact that Ss on a titration schedule often allow the stimulus to reach aversive levels indicates deficient avoidance behavior, which is especially surprising in monkeys because of the extremely effective avoidance behavior usually elicited from them (*e.g.*, Boren, 1960). Perhaps the reason can be inferred from the following argument. The probability of a response on a titration schedule is a function of shock level; the higher the level, the greater the probability. Shortening the *i-i* interval or

Fig. 10. Attenuator record made by human Ss under instructions to maintain shock level just below pain threshold. Time reads right to left and each segment represents the last 30 min of a 40-min session.

increasing the number of responses that the animal has to make in order to produce a decrement (either by imposing a fixed ratio or a smaller step size) is analogous in Sidman avoidance to shortening the response-shock interval or requiring more than one response to postpone the shock; these changes predispose toward an increased number of shocks, *i.e.*, a decline in avoidance efficiency (Sidman, 1953; Verhave, 1959a, 1959b). The fact that both decreases in i-i interval and step size produce analogous effects suggests that if there is a common basis for these effects it is that both reduce the amount of avoidance behavior present. The result of such a reduction must be a rise in the level of shock tolerated.

The fact that more shock is taken under more stringent requirements on the organism is not an isolated one. Other instances have been noted in other contexts. For example, Findley (1962) recently reported that pigeons working on complex schedules involving low or moderate fixed ratios tended to maintain their body weights at about 95% of the free-feeding value. When the ratio requirement was raised markedly, the body weight was maintained at about 85% of the free-feeding weight. Teitelbaum (1957) reported a similar result in his studies of hypothalamic hyperphagia. He found that when a fixed ratio was raised beyond a certain point, the number of pellets taken by the rats fell markedly, and the rats maintained their intake at a lower level. The point at which this occurred was lower in those animals having ventromedial hypothalamic lesions than in normals. Our work on the behavioral regulation of body temperature offers an analogous finding (Weiss and Laties, 1961b). In this situation, rats worked for heat by pressing a lever that turned on a heat lamp. Over a wide range of lamp outputs, they maintained a constant peripheral temperature by raising or lowering response rate in accordance with the lamp intensity. However, when the intensity was very low, making it necessary for the rat to

respond at a very high rate in order to obtain the same total amount of heat, rate did not rise accordingly. The rats simply tolerated a lower skin temperature. It therefore appears to happen frequently that the greater the required output of behavior, the greater the deviation of a behaviorally regulated variable from its normal or optimal level.

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